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<p>The "Danish Deep Drill" was developed at the University of Copenhagen. The drill, which will be used to obtain ice cores from the Greenland Ice Sheet, was tested at the U.S. Army Cold Regions Research and Engineering Laboratory.</p> <p>The drill is battery-operated and has a down-hole microprocessor-based control section and a delicately balanced chip removal system. It is a lightweight, electro-mechanical drill designed to obtain a 10.2-cm-diameter core in 2-m lengths.</p>		

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20. Abstract (cont'd)

There are potential problems in chip recovery and storage, malfunctions of the computer or batteries, leaks in the pressure chamber, spin-out or rotation of the drill, and the very close tolerances required by the drill design. Tests are recommended that will help eliminate some of these potential problems and determine the drill's overall strengths and weaknesses.

The drill is a very complex and delicate instrument that will require constant maintenance, modification and monitoring when in use.

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PREFACE

This report was prepared by John Rand, Mechanical Engineer, Engineering and Measurement Services Branch, Technical Services Division, U.S. Army Cold Regions Research and Engineering Laboratory. The report covers work done for the National Science Foundation under Interagency Agreement NSF-DPP 78-17165.

The report was reviewed technically by Donald Garfield and Herbert Ueda. The photographs in Appendix A were taken by Dr. Sigfus Johnsen.

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INTRODUCTION

The University of Copenhagen, Denmark, is developing a drill for obtaining ice cores from the Greenland Ice Sheet. The Division of Polar Programs of the National Science Foundation is sponsoring a major portion of this effort. As a part of the two-year testing program for the drill, Dr. Sigfus Johnsen and Mr. Jan Neilson tested the drill's down-hole components at the U.S. Army Cold Regions Research and Engineering Laboratory in February and March 1979.

Tests were conducted to evaluate the potential and actual performance of the "Danish Deep Drill." While it would have been more desirable to test the various components and systems while they were being fabricated, the construction phase components were often not available for testing in the most logical sequence.

DESCRIPTION OF THE DRILL

The Danish drill is an electromechanical ice-coring device suspended on a 6-mm cable from a tower and winch assembly. Overall the drill is 12.8 cm in diameter and 10.2 m long; it weighs approximately 160 kg. It drills a hole 12.9 cm in diameter and obtains 10.2-cm-diameter core approximately 2 m long. The core and cuttings are collected in separate storage areas within the drill and hoisted to the surface for removal.

The drill incorporates several unique features. The chip collector sucks up the chips in much the same way a syringe sucks up fluids. A down-hole computer monitors certain drilling parameters, and can control the drilling operation if desired. A hinged tower assembly can bring the drill to a horizontal position, facilitating core removal and drill servicing. The drill fits snugly into the hole it produces, with very small clearances.

The drill comprises several components with different functions. These are illustrated in Figure 1 and described below, starting at the top of the drill.

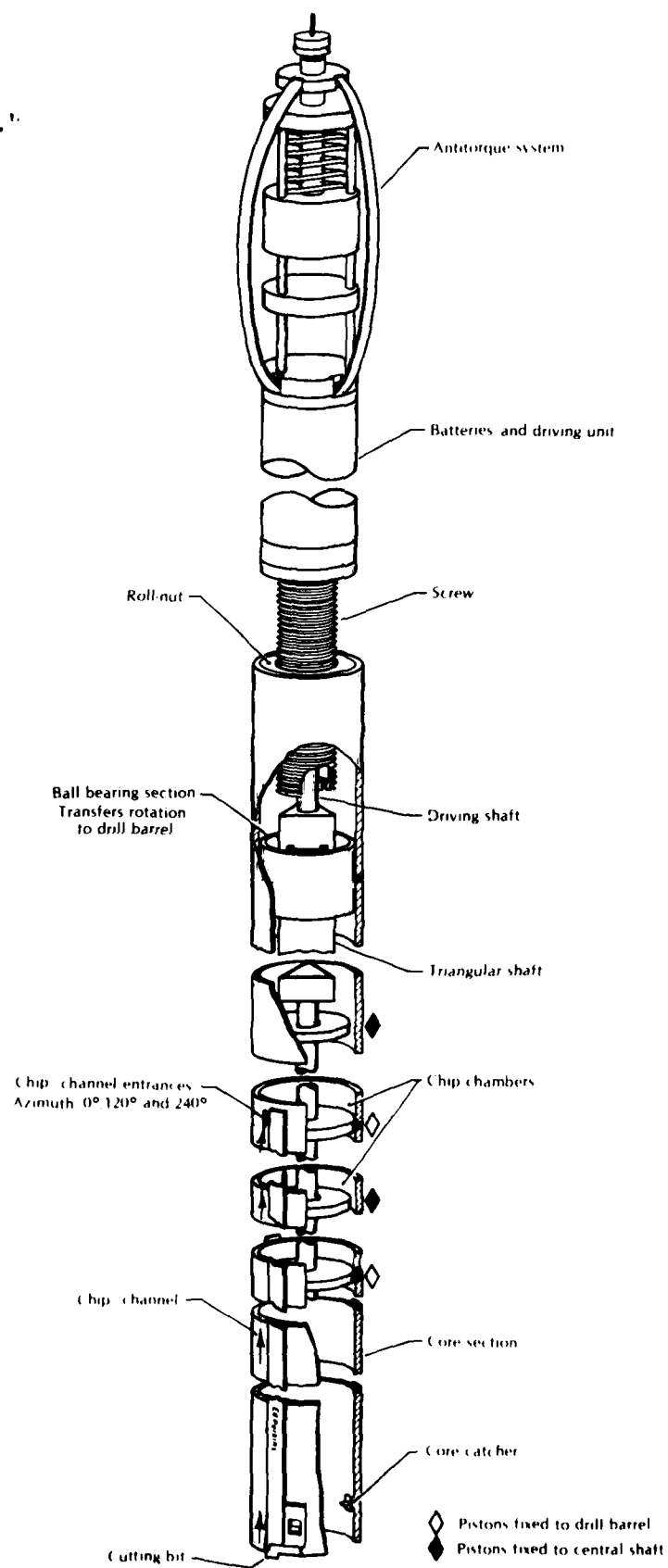
Antitorque section

The antitorque section includes the cable termination, the anti-torque springs, the weight indicator, and the steel hammer block.

The commercially available "Dyna-Grip" cable termination mechanically attaches the cable to the drill while allowing the electrical leads within the cable to pass through to the electronic package.

The antitorque spring assembly consists of three leaf springs arranged to contact the hole wall and create frictional forces that resist the drilling torque. The leaf springs are 50 cm long by 2 cm wide and come in various thicknesses. The 2-mm-thick leaf springs apply

Figure 1. Main components of the "Danish Deep Drill."



a 44-kg radial force against the hole wall. By increasing the thickness of the leaf springs to 2.5 mm, a 71-kg radial force is developed. As the radial force increases, the resistance to rotation also increases. The free shape of the springs is that of a fourth order parabolic, allowing a uniform loading along the entire length of spring in contact with the hole wall.

The weight indicator is contained inside the housing that supports the externally mounted antitorque springs and consists of a coil spring whose deflection is measured by a linear potentiometer. As weight is transferred from the cable to the cutters, the partially compressed spring relaxes. Given the spring constant, the spring displacement measurement can be calibrated to produce a direct indication of the bit force. The linear potentiometer is enclosed in a liquid-sealed container to prevent an electrical short circuit.

The final component in this section is the steel hammer block. This device develops a shock to break the core at the end of each coring run. When the run is completed, the cable is slackened until the 7-kg hammer is resting at the bottom of its 10-cm-long guide. The hoisting system is then started, accelerating the hammer block upward until it hits an anvil rigidly attached to the drill. The Danish drillers feel that an impact is much more effective than a steady pull for breaking the brittle ice cores.

Sealed chamber section

The sealed chamber contains all of the electrical components and is designed to withstand external pressures of 20.7 MPa. Internal components include the battery pack, the computer, the motor and the gear reducer.

The battery pack consists of 55 nickel-cadmium batteries housed in an insulated container. These batteries are SAFT type VR 1.8 rated at 1.8 volts, 1.2 amp-hours at 7 amps. The battery pack also contains a number of thermistors to monitor the battery temperatures. Semiconductor switches eliminate electrical arcing. There is a potential hazard here because the batteries may emit hydrogen gas during the charging and discharging cycles. If the hydrogen gas is not properly monitored and controlled, a small electrical spark could ignite it.

A down-hole computer is stationed below the battery pack. The computer monitors and controls various functions down-hole and sends information to recorders and a visual display on the surface. Manual override switches allow the operator to control the drill from the surface. At the time of this report specific information on the computer and its functions was not available.

A variable speed d-c motor and harmonic drive gear reducer occupy the lower part of the sealed chamber. The main driveshaft extends from the gear reducer through a mechanical seal at the bottom of the chamber and is coupled to the screw section below. The Teflon seals are designed to maintain the integrity of the entire sealed chamber section. However, a leak detector within the sealed chamber will indicate any fluid accumulation should leakage occur.

Screw and roller nut assembly

This assembly converts the rotary motion of the drill into linear motion, which is used to operate the chip collection system. The assembly is located inside the top of the core barrel. A hollow screw is rigidly attached to the bottom of the sealed chamber and does not rotate. The main driveshaft extends through the hollow screw and is supported by bearings at the screw's upper and lower ends. Rotary motion of the main driveshaft is transmitted through a triangular shaft and a linear bearing assembly to the core barrel. A roller nut attaches to the top of the core barrel and engages external threads on the hollow screw. This nut rotates with the core barrel to complete the conversion from rotary to linear motion. This mechanism advances the drill a predetermined amount for each revolution of the cutter head. The components were chosen and arranged to provide the desired movement while retaining longitudinal stiffness in the section.

Core barrel assembly

The core barrel assembly consists of the chip collection chambers, chip transport channels, cutting bits, and core catchers. This assembly is the longest drill section (5 m of the drill's 10 m total length). As previously described, the screw assembly is located inside the top of the core barrel. Coupled below the triangular shaft is a small diameter rod to which three pistons are attached at equal intervals. Each piston moves vertically in a sealed chamber. Each chamber has only one inlet, a channel extending the length of the core barrel to a point just above a cutting bit. Each chamber also has a sealed cleanout door for removing the ice cuttings. Vent holes at the top of each chamber expel fluid from above the piston subassemblies. As the core barrel assembly moves down with respect to the pistons, a vacuum is generated within each chip collection chamber. The vacuum draws the mixture of drilling fluid and chips through channels to the chip collection chambers. The downward motion also displaces the clean drilling fluid that has been placed in the space above each piston into the hole, providing a supply of new drilling fluid to replace the volume of ice removed. Directly below the chip collection chambers is space for core retention. This space is merely a cylindrical chamber slightly over 2 m long with the core catcher and cutters below.

Cutters and core catchers

Three cutting bits are equally spaced around the bottom of the core barrel. Chips produced at each cutter are directed upward through separate chip collection channels to the chip storage area. Particular attention was paid to the sharp cutting edges. Stopper shoes behind the cutters control the cutting depth. Five different shoe depths provide flexibility in penetration rates. The core catchers are spring-loaded, dog-leg-shaped blades which engage the side of the core as the drill is raised, breaking the core and retaining it within the core barrel. Three catchers are spaced equally around the core barrel near the cutters.

POTENTIAL PROBLEM AREAS

Dr. Johnsen and his colleagues have identified a number of potential problems. Tests have been planned to evaluate the performance of critical components.

Chip recovery, storage, and removal

The Danish drill's success, as with all electromechanical drills, depends on its ability to remove cuttings from the bit and store them. In the Danish drill the cuttings will be mixed with drilling fluid and drawn through channels to the storage containers. If the drill does not remove the cuttings correctly, they will block and bind the bit.

Pressure chamber seal leakage

There is a dual mechanical seal on the rotating shaft where it exits from the pressure chamber. This design differs from most submersible chambers, which are filled with a liquid and pressure-compensated to maintain an internal pressure slightly higher than the external environment, eliminating the possibility of leakage into the chamber. Although the Danish designers anticipate no problems with seal leakage the system has monitors at both the first and second seals to detect any leakage.

Battery operation

Several engineers have questioned the utility and safety of the battery package in the Danish drill. The battery package and its charging system will be monitored very closely throughout the drilling operation.

Computer operation

Although the drill can be operated manually, the down-hole computer will continuously provide important information. The computer's multiplexing capability decreases the number of signal and control conductors required in the electromechanical cable. The cold environment may pose problems for both the surface recorders and the down-hole electronics.

Antitorque system

The rotation and advance of the cutters depends on satisfactory performance of the antitorque springs. The force exerted against the hole wall must be large enough to prevent the drill from spinning out, yet small enough to minimize drag when the drill is hoisted or lowered. Experience indicates that this system will function properly under normal drilling operations. However, the springs may slip if excessive penetration rates are attempted.

Chip collection system

Although the chip collection system is relatively simple, at least two potential problems are apparent. It is essentially a vacuum system

and so is very sensitive to any leaks. The integrity of the system requires periodic checks, perhaps before every drilling run. The chip collection system is directly driven by the main driveshaft, so the system is operating whenever the drill is rotating, regardless of whether the drill is actually cutting ice. Therefore, the system limits the down-hole drilling time to a certain number of drill rotations, not generally related to a given core length.

Clearance between drill and ice

The extremely small clearances between the drill and the hole wall raise concerns about the antitorque system operation, the passage of the drill through the drilled hole, the ability of the core barrel to accept core, and the ability to obtain good quality core.

Core recovery and removal

The core catchers on the drill have worked very well in previous tests. However, as with all drills, if all of the core is not recovered after each run considerable time may be consumed trying to remove the core left in the hole. Removing the core from the drill should only be a problem if the core is oversize and sticks inside the barrel.

RECOMMENDED PERFORMANCE TESTS

Winch hoisting capabilities

Although not directly related to the down-hole portion of the drill, the winch capabilities must be completely checked out. The following operational checks should be performed: maximum lifting capabilities; hoisting and lowering speed control; proper spooling action on the drum; maximum safety protection for all rotating sprockets, chains, and belts; and computer and manual override controls.

Chip recovery

The following procedure measures the effectiveness of the chip recovery system. A. Measure the volume of chips collected by melting the chips in the drilling fluid chip mixture, allowing the drilling fluid and the water to separate, and measuring the resulting volume of water. The equivalent ice volume can be calculated from the water volume. B. Measure the exact core diameter and length. Assume all the core was recovered on that particular run. C. Measure the hole diameter. D. Calculate the volume of ice cut for the run. E. The equivalent volume of ice recovered divided by the volume of the ice times 100 is the chip collection efficiency of the system.

Antitorque system

It is important to know the breakaway torque of the antitorque system. To measure the breakaway torque a torsion load cell must be

coupled between the bits and the antitorque skates. The breakaway torque should be greater than the stall torque of the drill motor. The frictional drag forces must be less than the submerged weight of the drill to allow for proper bit forces and for smooth lifting and lowering. The torsional resistance of the skates can be read directly from the torsion load cell for a variety of penetration rates at a constant rate of rotation.

The forces on the bit during each test should be recorded. The maximum torque capabilities of the various skates can be determined from data obtained.

Fluid leakage in pressure chamber

The pressure chamber should be subjected to external hydrostatic pressures similar to those experienced while drilling. The chamber should be tested for over 1200 cycles, but this is probably not possible due to time limitations. The chamber should be tested for a minimum of 400 cycles. Once the number of cycles has been determined, the test pressures should be estimated. The pressure should be increased in regular intervals to a maximum pressure of 20.7 MPa. The sequence of the tests should be: A. The chamber is slowly subjected to test pressure. B. The motor is turned on and allowed to run to simulate a full drilling run. C. The motor is shut off and the pressure reduced to atmospheric conditions. D. During the pressurization and drill motor rotation, the leak detectors should be monitored. If a leak develops the test should be stopped, the chambers opened, and the fluid leakage measured. Some leakage may be acceptable if the internal components are not damaged and the chamber can be easily drained. If no leakage is noticed, the next test should be conducted.

Test of batteries under environmental conditions

The batteries should be charged and discharged the number of times that will be required to complete the proposed Greenland deep hole drilling project. This test should be conducted at the same time as the pressurization test. Particular attention should be given to battery outgassing, which could cause an explosion in the sealed container. During the test, charging and discharging rates should be as close to field values as possible. The battery charging current, terminal voltage, and temperatures should be measured during the test to ensure there are no problems.

Cable termination strength

A "weak link" should be designed in the upper components of the drill to fail at 80 percent of the cable's design load. This weak link should be below the triangular shaft. A second weak link designed to fail at 90 percent of cable breaking strength should be located in the cable termination. In either case a junk basket should be used to recover drill components left down-hole.

Mechanical characteristics of the cable

Copies of the certified manufacturer's tests should be obtained. Tests that should have been made are:

- A. Cable length
- B. Diameter of cable measured every 100 m
- C. Load-strain relationship from zero load to breaking strength, with and without ends fixed
- D. Cable breaking strength
- E. Cable rotation and torque versus load
- F. Electrical breakdown voltage with cable bent past minimum bending radius

Electrical characteristics of cable

Certified copies of the manufacturer's electrical tests should be obtained. Tests should include:

- A. Measured ac and dc line resistance
- B. Measured resistance to ground on each conductor
- C. Measured capacitance between conductors and from conductors to ground

Winch hoisting capabilities

The winch should be tested several ways when it is assembled with the cable. The maximum cable tension at the stall torque of the winch motor should be measured. The maximum hoisting speeds under load and as a function of load and depth should be measured. The performance of the winch at slow speeds should be checked to ensure that it can provide the low speeds required for drilling.

CHRONOLOGICAL SEQUENCE OF TESTS COMPLETED

On 22 February 1979 the Danish drill was completely disassembled for inspection at CRREL. Problems were immediately noted in the chip storage section and along the chip channels. Additional problems were noticed in the piston assemblies and the air vent valves. The majority of the problems were due to poor craftsmanship. Work was initiated on the piston assemblies. The chip channels were re-epoxied where obviously necessary. Problems were also noticed in the cutters, where the tube was out of round. During its manufacture, three long grooves had been machined along the axis of the tube, 120 degrees apart. It was felt that the out-of-roundness was caused by the large amount of machining. Inspection of the lower portion of the tube showed it had a pear-shaped cross section, with the worst problem in the lower 10 centimeters of the drill. The cutters were modified to correct for the out-of-roundness.

When the piston assembly was first disassembled it had to be forcibly removed. This action damaged the seals and the vent assemblies and threatened the joints between each assembly. Additional damage was noticed on the inside of the core barrel. Pieces of material had become lodged in the seals, scoring the barrel. A system was developed to eliminate the damage when disassembling and assembling the inner components. A gage simulating the hole diameter was passed along the outside surfaces of the channels. When this gage was passed along the channels, it was noticed that the channels were "sticking out." In the areas where the channels were out too far, the welds and epoxy seams had to be removed and the channels clamped into proper orientation. The channels were then soldered and epoxy-sealed. Vacuum tests were made on each of the three channels to determine if there were any leaks.

The initial tests on each of the three channels showed between 250 and 300 mm of mercury. Major leaks were detected in the epoxy seal along the entire length of the channels. The three chip channels were identified in the following manner: channel 1 is the shortest, channel 3 the longest. After repairs were made, channel 1 had a vacuum of 450 mm of mercury, Channel 2 a vacuum of 350 mm of mercury, and Channel 3 a vacuum of 200 mm of mercury. At this time the major leaks were in the air vent valve assembly. The core barrel was checked for tube straightness. The area along channel 1 had the greatest error; the error was about 4 mm 4 m from the bottom. The total core barrel length is about 5 m.

The channels have a slight taper towards the center of the drill when viewed from the bottom of the drill looking up towards the screw and roller nut assembly. This means there are only two points of contact between the hole wall and drill: the bottom of the channels near the cutters and the antitorque springs at the top.

The total bend in channel 1 (short one) from one end to the other was about 2 mm. The piston assembly tube and the core barrel had been welded together to make one barrel 5 m long. The straightness was considered acceptable.

On 6 March, the pistons were reassembled and a vacuum test performed. All three channels had a vacuum of over 460 mm of mercury, showing improvements in the valve assemblies and reduction in the leaks along the channels. The cutter assemblies were modified slightly by adding pieces of shim stock to align the cutters properly.

Five sets of cutter standoff shoes had been made to vary the penetration rate of the drill. These shoes were identified by numbers from 1 to 5. The corresponding calculated depth for one complete drilling cycle is as follows:

1. 1.09 m
2. 1.45 m
3. 1.79 m
4. 2.14 m
5. 2.49 m

The calculated mixing ratio of ice cuttings to drill liquid is defined as the volume of chips divided by the total volume (drill liquid plus cuttings). The mixing ratio with the various shoe standoffs had been computed to be as follows.

<u>No.</u>	<u>Percent</u>	<u>Pitch</u>
1	20	4.68 mm
2	32	6.18 mm
3	40	7.65 mm
4	48	9.15 mm
5	55	10.65 mm

Shoe No. 3 was used in the majority of the tests performed at CRREL. The dimensions of the core and hole were 102 mm and 129 mm, respectively, giving an annulus area of 47.86 cm². The volume of the piston area for one complete stroke is 7.2 liters.² The area of that section is 76.8 cm². The area of the channels is 2.1 cm². For every meter of hole depth 13.1 liters of drilling fluid is required. The drilling fluid, used to prevent the overburden pressures in the ice from reducing the hole diameter, is a mixture of Jet-1 fuel and tetrachlorethylene having a density of 0.92 g/cm³. On 9 March the drilling fluid was initially mixed. Problems were encountered in the method of mixing. The Jet-1 fuel was initially added and chilled to -26°C. The tetrachlorethylene was then added. No noticeable change in density occurred since tetrachlorethylene freezes below -22°C. Mixing this solution required higher temperatures. Density profiles were made for each of the two liquids as a function of temperature. From these it was determined that the temperature of the mixture had to be above +10°C before proper mixing could be obtained. Drill tests were started on 11 March. Descriptions of the various runs are included in the drill log (Appendix B), which has been prepared from Dr. Johnsen's taped description of the tests.

COMMENTS AND CONCLUSIONS

The testing period at CRREL was the first time that Dr. Johnsen had been able to devote his full attention to the drill without interruptions from teaching responsibilities. Also, many of the components of the drill had not been checked prior to arrival. Time, or the lack of time, played a key role in the problems encountered at CRREL. The work accomplished was crucial to the program. Although the effort turned out to be more of a debugging exercise than a test program, without it a very expensive time delay would have been experienced at DYE 3 during the drilling season.

Specific areas in which there has been improvement as a result of the time spent at CRREL are described below.

1. The initial assembly of the components of the core barrel section, principally the channels, created the major delays. These channels were initially spot soldered and epoxied. After many problems with leaks, the channels were completely removed and soldered along

their entire length. Figures A1-A7 (Appendix A) illustrate the various phases of this operation. Because of this time-consuming problem, it is recommended that a vacuum check on the channels be made at the start of each run. Very little time is required to make this check, but without a perfect vacuum there is a high probability that cuttings will plug one or all of the channels. Figure A8 shows a vacuum test on a channel.

2. The redesign of the air bleed valves was necessary to reduce leakage in the vacuum section. The major problem was that a fixed ball on the end of a spring would not seat properly. A floating ball system was built and improved the sealing action. This valve remains a very sensitive device. Perhaps even normal use in the field will create a continuing problem for the vacuum system (Fig. A9-A12).

3. The removal of the piston assembly is a delicate procedure. To work on the components in the piston area the entire piston assembly has to be removed. Piston seals are easily damaged during this operation. Extra seals should be on hand. A cable and winch assembly is attached to the piston rods to pull them out slowly. Figures A13 and A14 illustrate this procedure.

4. As described earlier, three different cutters were built to help direct the flow of cuttings into the channels. Figure A15 shows the three designs. The major problems at this end of the drill were related to tube roundness. Shims were placed between the barrel and the cutter mounts to correct cutter alignment.

5. The modification made to the lower channel entrance improved the flow of cuttings into the channels. Figures A19 and A20 show before and after shots of this area.

6. The screw and roller nut sections and the triangular shaft perform well. No problems developed. Rust could be a major problem if the drill is allowed to stand unprotected for long periods of time. Figures A22-A25 show the various sections and their method of attachment.

7. Only minor problems were experienced with the antitorque skates. Modifications to the skate pivot holders solved the problems. Replacing skates to change antitorque forces is accomplished by removing the screws as shown in Figures A26-A28.

8. The fluid systems make core removal a messy operation. Protective clothing is necessary. No major problems were experienced. However, improvements could be made to reduce the amount of spillage in the work area.

9. The battery pack was sent to CRREL for test runs. Only one run was made with the batteries installed in the system (see Fig. A35). There was no provision for recharging batteries at CRREL.

10. The assembled drill and winch platform are shown in Figures A36 and A37.

Two statements can summarize the observations made while the drill was at CRREL. The drill is a very complex and delicate instrument. It will require constant and intensive maintenance, modification, and monitoring when in use.

APPENDIX A: PHOTOGRAPHS



Fig. A1.

Epoxy separating from core barrel and channels at a solder joint.



Fig. A2.

Once the epoxy seal had been removed, it exposed the sloppy craftsmanship of the soldering. The dark lines are the flux which had not been cleaned off prior to epoxying.

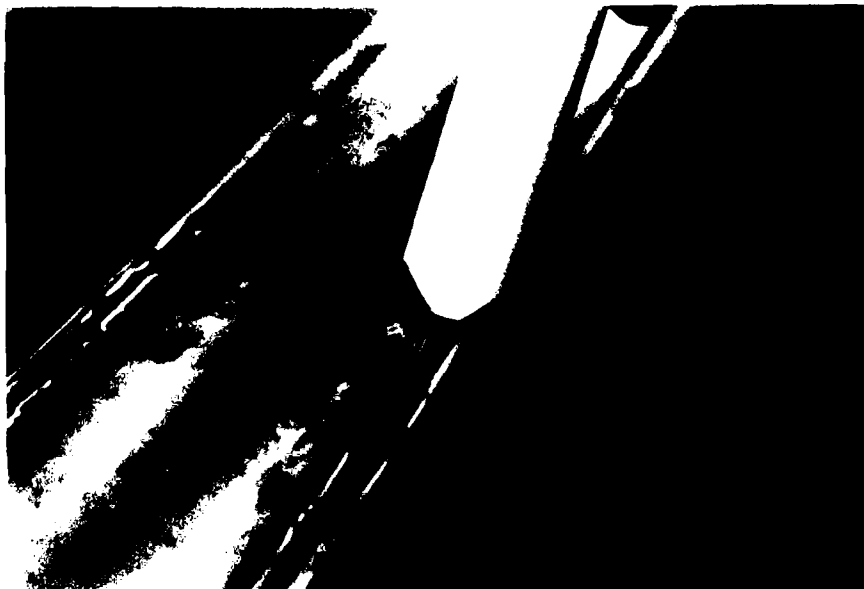


Figure A3.

After the joints between the drill and channel were cleaned, an epoxy seal was applied.

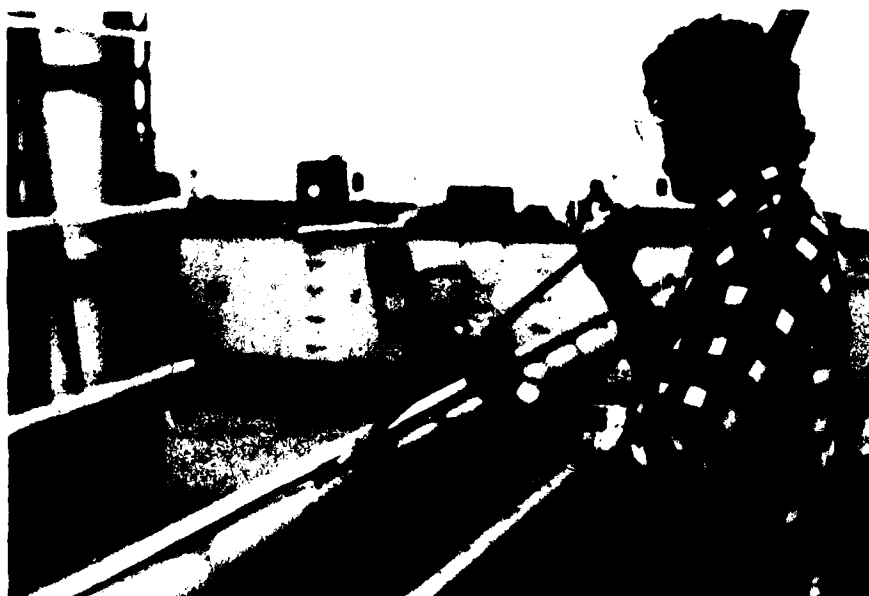


Fig. A4.

The channel was later completely removed. Even after thorough cleaning of the drill and re-epoxying, cracks developed.



Fig. A5.

Channel being removed from drill. Note the epoxy partially filling the inside of the channel, reducing its cross-sectional area.



Fig. A6

Once the channel had been removed and cleaned, the channel was soldered the complete length of the barrel.



Fig. A7.

Final pressure test on channel shows a leak still remaining at the top.

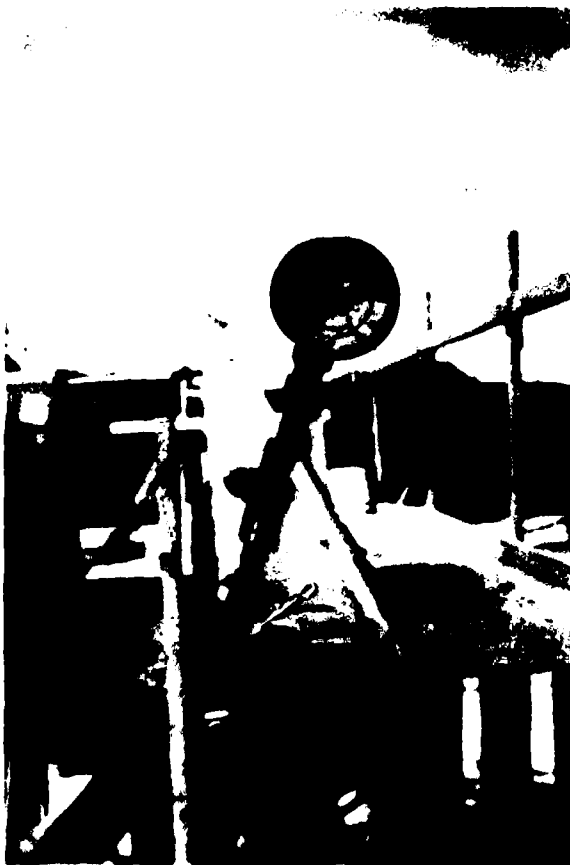


Fig. A8.

Vacuum test on channel.



Fig. A9.

The ball assembly on the right is the rigid system. The three assemblies on the left show the design change.



Fig. A10.

The ball is contained by three fingers. The floating action allows the ball to seat properly.

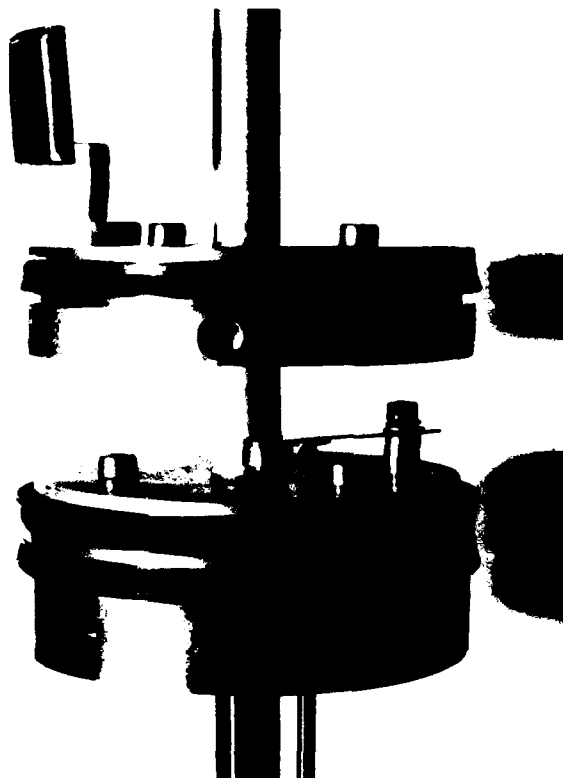


Fig. A11.
The ball assembly
in the piston.

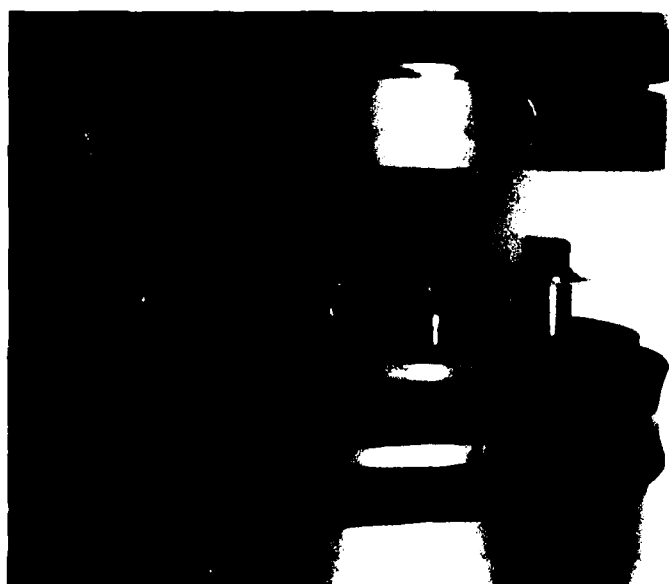


Fig. A12.
A closeup of the ball assembly.



Fig. A13.
Removing the pistons.



Fig. A14.
Piston seals may be damaged during disassembly when
they pass the leading edge of this opening.



Fig. A15.

Cutters. Cutter number 3 was used for most of the drilling at CRREL.



Fig. A16.

The light area between the center plug and bit illustrates the out-of-roundness of the barrel.



Fig. A17.

Shim stock placed between
cutter mounts and barrel
corrected alignment problems.

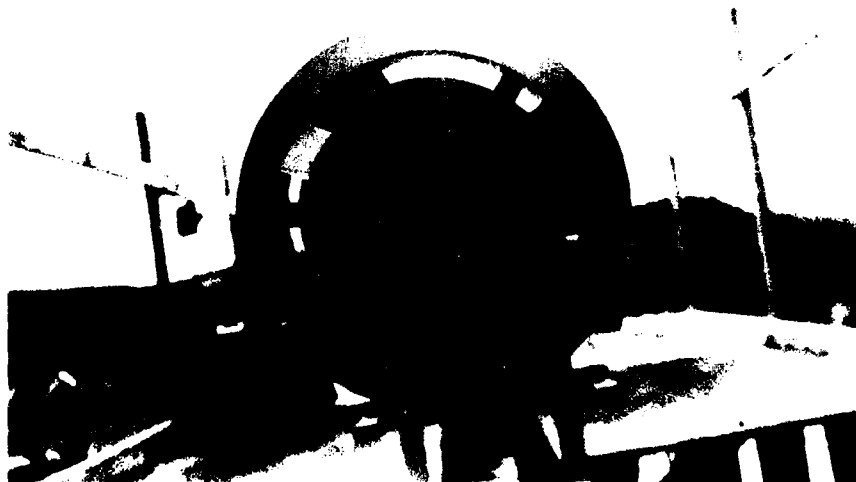


Fig. A18.

The center plug and the outer gage installed to show the
final cutter alignment.



Fig. A19.
The lower left-hand part of
the channel created continual
problems.

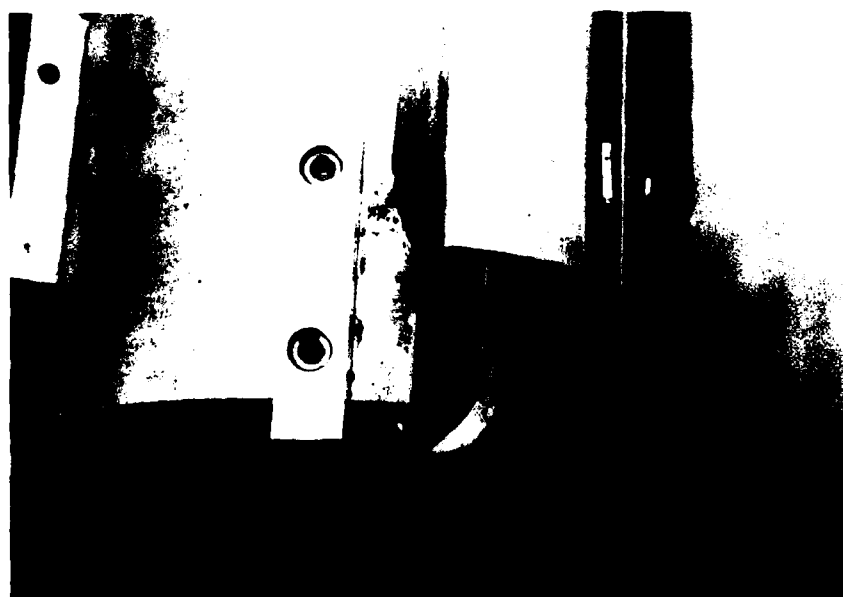


Fig. A20.
Lower channel after modifications.

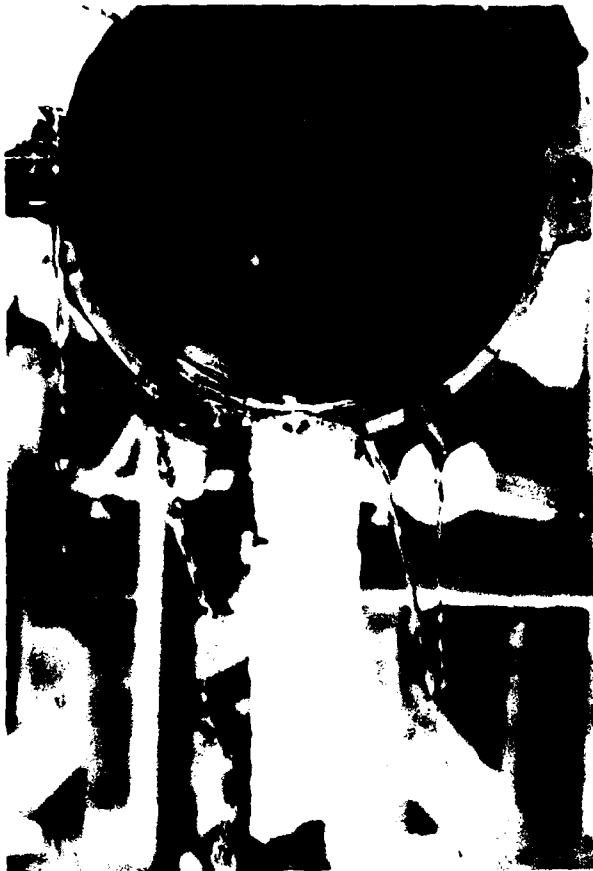


Fig. A21.
Cutting being removed from
channel.

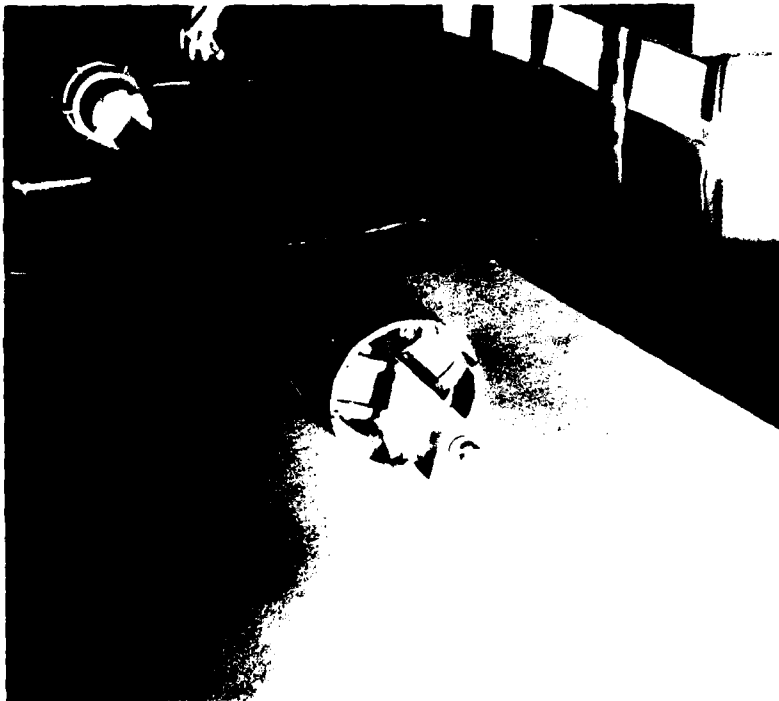


Fig. A22.
Triangular shaft
and bearing assembly.

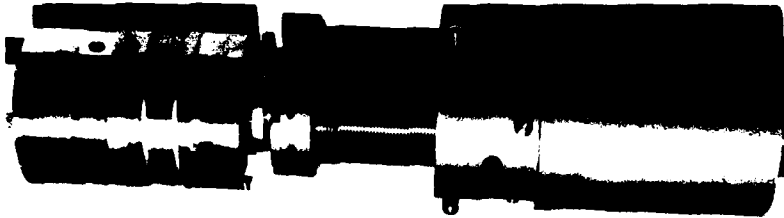


Fig. A23.

The ball screw
assembly on the
left, the triangular
bearing on the right.

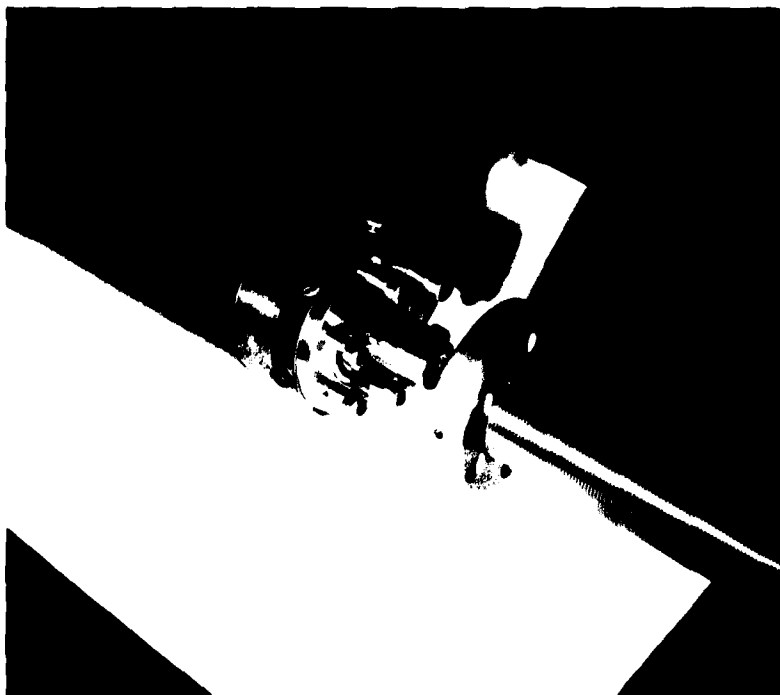


Fig. A24.

The motor flange and
top section of screw
assembly.



Fig. A25.
Screw assembly coupled
to motor.



Fig. A26.
Adjustments being made to antitorque skates.

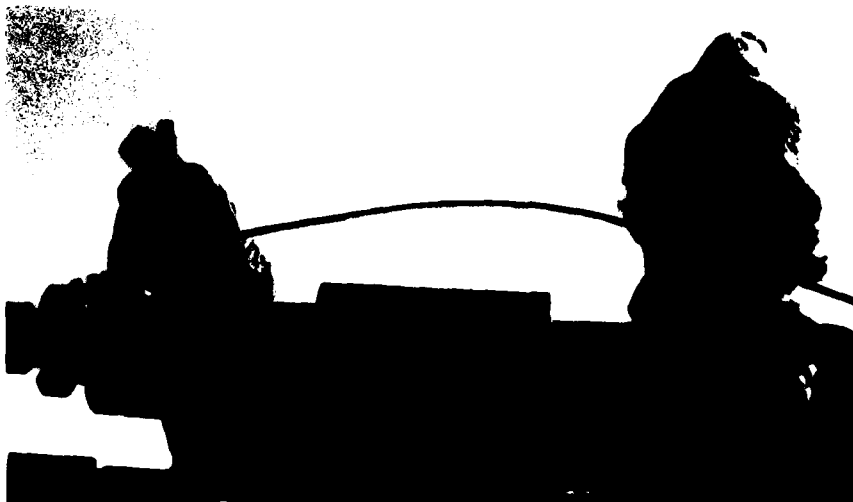


Fig. A27.
Antitorque skates in assembly.



Fig. A28.
The antitorque skate pivot assembly. The cable
termination and hammer are inside the skates.

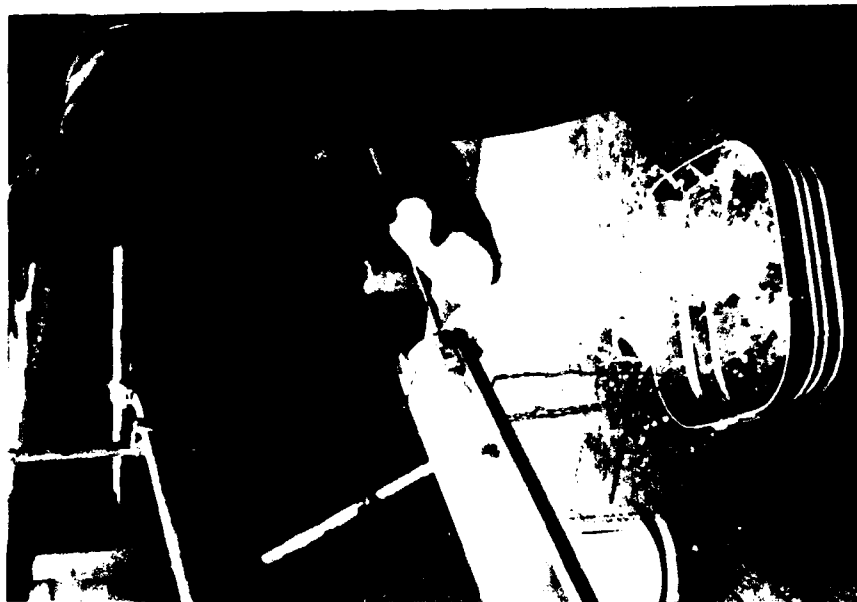


Fig. A30.
Drilling fluid splashing out.



Fig. A29.
Core being removed from barrel.



Fig. A31.
Ice cuttings from chip storage chamber.



Fig. A32.
Filling area above chip
storage compartment with
drilling fluid.



Fig. A33.
Checking density in mixing tank.

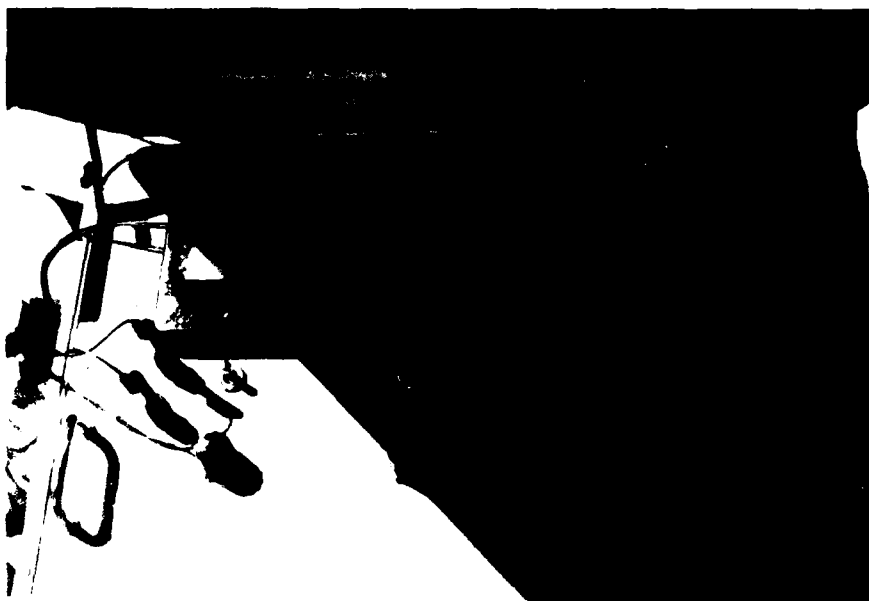


Fig. A34.
Control station for drill and winch as used at CRREL.

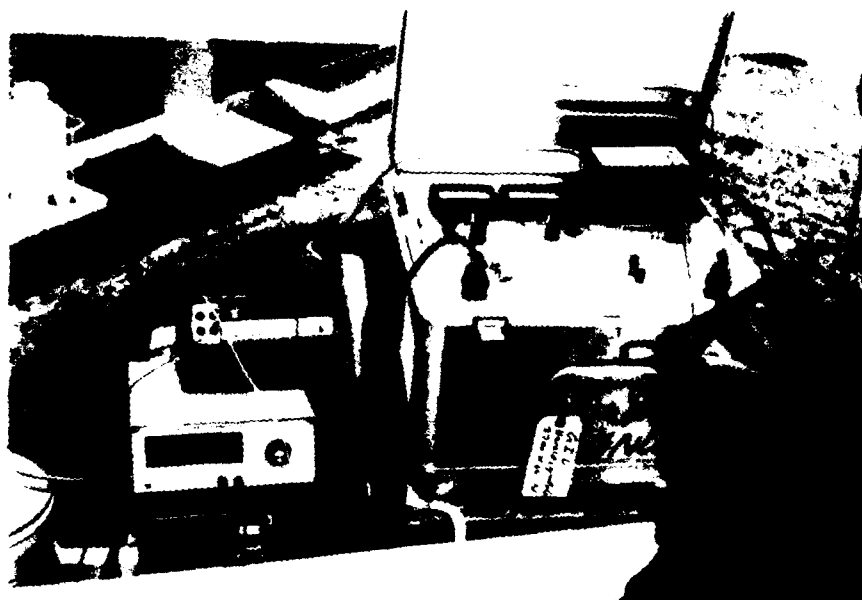


Fig. A35.

Control station with battery packages.



Fig. A36.

Assembled drill. The aluminum gage and plug are removed before drill is sent down-hole.

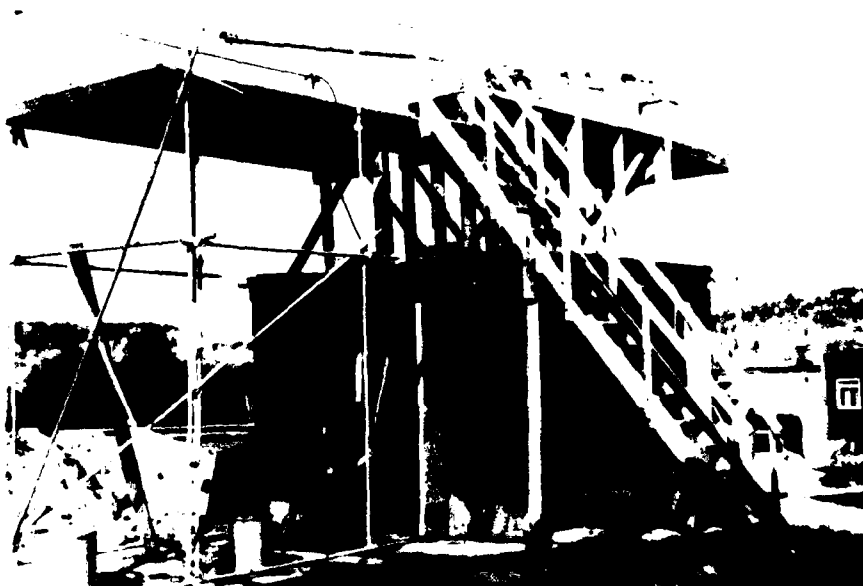


Fig. A37.

Test platform for Danish drill. Top deck was 5 m
above ground.

APPENDIX B

Danish Drill Test Core Log - March 1979 (Prepared from a taped conversation with Sig Johnsen)

<u>Date</u>	<u>Run #</u>	<u>Starting Depth (m)</u>	<u>Core Length (cm)</u>	<u>Cutters Used</u>	<u>Stopper Shoe #</u>	<u>Voltage (V dc)</u>	<u>Current (A)</u>	<u>Comments</u>
11 March	1	10	0	3	3	100	2.8	A number of problems were encountered during the first few runs. The anti-torque skate assemblies had to be modified to change the hole contact diameter. The thermal drilled hole walls were rough and uneven. It was raining, and rain and melted snow dripped down the sides of the wall, creating problems in raising and lowering. A low vacuum on channel three was noticed after ice cuttings plugged it. An improperly assembled section in the screw and roller nut assembly was noticed.
13 March								Mr. Karl Kuvinen and Dr. Langway visited the laboratory to review the progress of the test.
14 March								Refrigeration to the test facility was shut down. Hole temperature -34°C. After 4 hrs the temperature increased to -30°C.
17 March	4	10.2	20	3	3	100	2.8-3	Drill rotated.

<u>Date</u>	<u>Run #</u>	<u>Starting Depth (m)</u>	<u>Core Length (cm)</u>	<u>Cutters Used</u>	<u>Stopper Shoe #</u>	<u>Voltage (V dc)</u>	<u>Current (A)</u>	<u>Comments</u>
18 March	5	10.2	18	3	3	100	2.8-3	Screw movement was 30 cm. Drill rotated at 5 A, #3 channel plugged. Side cracks noticed in core. Large chips down hole.
18 March	6	10.2	0	3	3	100	2.8-3	20 sec drill run, drill rotated at 5 A, no core.
18 March	7	10.8	30	3	3	100	3	Drilled for 1 min 30 sec, both channel #1 and #2 plugged.
18 March	8	11.1	0	1	3	100	3	It is standard practice to start drill 10 cm above bottom of hole. It takes 20-30 seconds for the screw to travel that distance at the start of each run. 45 sec drilling time, channel #3 plugged.
18 March	9	11.1	0	1	3	100	3	Very poor run, all channels plugged.
18 March	10	11.2	0	1	3	100	3	Same problem. Removed leading edge of channels near cutter.
19 March	11	11.3	90	3	3	100	2.8-3	Drilling time was 4 min 30 sec, good core, stable run. Improvements to the channel entrance seemed to help.
19 March	12	12.2	94	3	1	100	2.8-3	During the end of run slack was given to cable to see how drill performs with full weight on drill.
20 March	13	13.1	0	3	2	100	2.8-3	No penetration, ice probably formed on cutters and in channels. Channel might not have been cleaned from previous run.

<u>Date</u>	<u>Run #</u>	<u>Starting Depth (m)</u>	<u>Core Length (cm)</u>	<u>Cutters Used</u>	<u>Stopper Shoe #</u>	<u>Voltage (V dc)</u>	<u>Current (A)</u>	<u>Comments</u>
20 March	14	13.1	108	3	2	100	2.8	Full drill weight on ice, poor control of penetration, current increased rotation noticed
20 March	15	14.1	54	3	3	100	3	Drilled under tension for 15 sec then slack for 1 min 15 sec. Channel 3 plugged, rotation noticed.
20 March	16	14.6	117	3	3	100	Kept current under 3.5	Good run
20 March	17	15.8	134	3	3	100	Kept current under 3.5	Core diameter measured 102.5 mm
20 March	18	17.2	143	3	3	100	Kept current under 3.5	Longest run, the bottom portion of the skates was coming close to the bottom of the thermal drilled hole.
20 March	19	18.3	0					Made a short run to get to the bottom of starter hole. Replaced skates to fit smaller hole diameter.
21 March	20	19.3	55	3	3	100	3.1-3.2	Very warm day. Current increased to 3.5 A. Rotation noticed. Pulled up drill, adjusted tension on skates.
21 March	21	19.8	0	3	3	100	3.1-3.2	Drilled for 15 sec, #3 plugged.
21 March	23	19.8	0	3	3	100	3	Checked welds on channel, drill rotated, drill movement was jerky, no core, slush down hole.
21 March	23	19.8	93	3	3	100	3	Plugged after 45 sec drilling. Very fine chips produced during previous run. Bad spot on #3 channel, no vacuum on #3. Cracks in epoxy seam. Worked on the channels.

<u>Date</u>	<u>Run #</u>	<u>Starting Depth (m)</u>	<u>Core Length (cm)</u>	<u>Cutters Used</u>	<u>Stopper Shoe #</u>	<u>Voltage (V dc)</u>	<u>Current (A)</u>	<u>Comments</u>
22 March	24	19.8	0	3	3	100	3	645 mm Hg on channel #3. During run channel 3 plugged.
22 March	25	19.8	68	3	3	100	3.5-3.8	1 min drilling time, #2 channel plugged. Pitch measured 7.5 mm.
22 March	26	20.5 m	0	3	3	100	3	#1 channel packed, hard to empty channels. Very coarse chips, top flapper valve in channel removed.
22 March	27	21.3	87	3	3	100	2.8-3.0	Drilling time 3 min 30 sec, 1 min on screw initially, #1 channel packed. Pitch measured 7.5 mm, vacuum on #1 250 mm Hg.
23 March	No drilling, repair work on drill							
Vacuum test conducted again, channel #1 150 mm Hg. Decision made to remove all the epoxy and separate the channels from the drill.								
From the 23 to the 29, work on channels. Upon completion tube was good, vacuum checked. Channel #1 720 mm Hg, Channel #3 650 mm Hg. A few leaks in Channel #2 were fixed, oil film added to air valve assembly, #2 vacuum improved to 650 mm Hg.								
29 March	28	21.6	136	3	3	100	3.1	Cold weather. Core diameter 103 mm. (Larger than before) The cutters were examined. At least two of the cutters were out of position, and required time to fix. Time was running short. Decided to continue as is.
29 March	29		40	3	3	100	3	#2 channel plugged.

<u>Date</u>	<u>Run #</u>	<u>Starting Depth</u> (m)	<u>Core Length</u> (cm)	<u>Cutters Used</u>	<u>Stopper Shoe #</u>	<u>Voltage</u> (V dc)	<u>Current</u> (A)	<u>Comments</u>
29 March	30		50	3	3	100	3	#2 channel plugged, fixed leak in channel.
30 March								Removed pistons, applied epoxy to channel, #2 vacuum 660 mm Hg.
31 March								On assembly something went wrong. Pistons rotated. Removed again, re-paired damaged part. Vacuum tests, 1-705, 2-695, 3-650.
31 March	30	23.6	20			100	3.1	Drilling time of 45 sec, channel #1 packed, ice on cutters.
31 March	32		73			100-65	3.8-3	This run was the only run made with the battery pack. Long run but current fluctuated, cutters needed to be properly aligned.

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